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RELIABILITY GROWTH PROGRAMS OF MAJOR
WEAPON SYSTEMS IN THE AERONAUTICAL
SYSTEMS DIVISION

Clinton L. Campbell, Captain, USAF

LSSR 18-83

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New equipment may not have the required reliability after it is designed and built. Reliability growth is the improvement of the reliability of equipment resulting from correcting discovered defects. The author describes current reliability growth programs on five major weapon systems at the Aeronautical Systems Division of the Air Force Systems Command. In addition, the Component Improvement Programs for the engines used in three of those weapon systems are described. No single approach to reliability growth was determined to be the best because of substantial program differences and insufficient data.

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RELIABILITY GROWTH PROGRAMS OF MAJOR WEAPON SYSTEMS IN THE AERONAUTICAL SYSTEMS DIVISION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Systems Management

By

Clinton L. Campbell, BS
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CHAPTER 1

INTRODUCTION

Problem Statement

When new equipment is designed and built, it may not have the reliability required to meet the needs of the Air Force. Some of the reasons for the deficiencies are bad design, poor part and material selection, and poor workmanship in assembling the equipment. Nearly all equipment could be improved. Reliability growth is the improvement in the reliability of a piece of equipment resulting from correcting defects found in the equipment.

In the Aeronautical Systems Division of the Air Force Systems Command, reliability growth is the responsibility of the managers and engineers of the system program office (SPO) working on the equipment. Unfortunately, many of these people do not have experience with reliability improvement. They are not sure of the best way to improve the equipment. Reviewing previous programs would help these new engineers and managers gain knowledge in this area. The lessons of existing programs could be made available to the new people, helping them achieve their program requirements.

Background

Experience has shown that

> initial prototype models of complex weapon systems will invariably have inherent reliability and performance deficiencies that generally could not have been foreseen and eliminated in early design stages (DOD 3235.1-H, 1982, p. 9-1).

This is due to "initial design and engineering mistakes as well as manufacturing flaws" built into the equipment (Illinois Institute of Technology, 1976, p. 12). If the deficiencies are corrected the weapon system will become more reliable.

Reliability improvements can occur anytime over the life of the equipment. Ideally, the design phase is the best time to make changes, since the equipment has not been built. Then, changes in the equipment design usually requires changes only to plans and drawings. At that time, expensive hardware does not need to be modified or scrapped. Therefore, the Air Force and contractors are attempting to get designers to refine the design before the first equipment is made. Yet, despite the best efforts of designers, the initial reliability of the equipment often still does not meet the requirements and must be further improved.

Correction of the deficiencies can take two general forms. The first is the replacement of failed parts by working parts of the same type. In essence, the operation of the equipment screens the parts for weaknesses and the weak parts are replaced. The screened equipment does show a higher reliability. However, if an error in the design of

the equipment causes the first part to fail, the new part may fail for the same reason as the old part and no change in reliability will occur. Certainly this kind of corrective action will only effect the single piece of equipment being worked on. Also, this kind of correction cannot transfer improvements to other units of equipment since there is no attempt to remove the failure mechanisms (reasons for failure) and the same failure could occur again (Swett, 1979).

The second form of reliability improvement occurs when a failure is examined and the failure mechanism is identified. The failure could be due to the design, workmanship, or software. If it is a design problem, the design of the part or equipment is reviewed to see if the conditions that allowed the part to fail can be removed. If feasible, the design is changed to permanently remove the failure mechanism.

If the failure is caused by poor workmanship, the production process is reviewed and the necessary changes are made to keep the failure from recurring. For example, the correction could be to add a cleaning step before conformal coating a printed circuit board. All future equipment manufactured using the new process will benefit from the changes.

If the failure is software related, the programs for

the equipment are reviewed and debugged. While all possible errors are not likely to be found (the possible combinations of even a short program are very large), the error causing the particular failure can be removed.

Thus, the incorporated design, workmanship, or software change results in the reliability improvement in the equipment. As noted above, the improvements are permanent and they can be transferred to any new or modified piece of equipment. This improvement is called reliability growth.

Traditionally, reliability growth has been just identified with equipment hardware. For example, RADC's Reliability Design Handbook states:

> Reliability growth represents the resultant action to hasten a _hardware_ item towards its reliability potential either during development or during subsequent manufacturing or operation [emphasis added] (Illinois Institute of Technology, 1976, p. 12).

However, with the increasing importance of software, it is worthwhile extending the concept of reliability improvement to software as well as hardware. Therefore, improvements in both hardware and software result in reliability growth.

Definitions

Reliability Growth: For the purposes of this paper, reliability growth will be defined as the positive improvement in the reliability of equipment hardware or

software through the systematic and permanent removal of failure mechanisms.

Reliability: Reliability is the probability that an equipment will operate without failure for a specific time under stated conditions (AFR 800-18, 1982).

Scope

This research will examine the planned, proposed, and implemented reliability growth programs of five major weapon systems in ASD. The weapon systems are the B-1B, B-52, F-15, F-16, and the AGM-86B Air Launched Cruise Missile. Since reliability growth deals with the improvement of existing equipment, activities related to designing-in initial relability and to environmental stress screening to remove early (infant) failures in equipment will be excluded.

Research Objective

The purpose of this paper is to describe the reliability growth programs of various ASD system program offices. The information contained in this paper will be of interest to people seeking an overview of the current reliability growth programs for major weapon systems at ASD.

CHAPTER 2

RELIABILITY GROWTH

Reliability Growth Process

Reliability growth is an iterative process that includes the following steps:

1. Detection of failure sources,
2. Feedback of identified problems,
3. Redesign effort based on identified problems,
4. Building of improved hardware or software, and
5. Verification of improvements due to the redesign (DOD MIL-HNBK-189, 1981).

The rate at which reliability grows is dependent on how rapidly the above process is accomplished, the magnitude of the problems identified, and how effective the corrective actions have been in removing the failure mechanism without introducing new problems (DOD MIL-HNBK-189, 1981). Improvement cannot occur at a faster rate than the completion of all the steps in the process allows. For example, if many hardware failures were detected during testing and the necessary redesign accomplished, no growth would be seen until the changes were incorporated in new or modified hardware. "Any of these [above] activities may act as a bottleneck. The cause and degree of the bottleneck may vary from one development program to the next" (DOD

MIL-HNBK-189, 1981, p. 6).

Reliability Growth Curves

For a system under development, the reliability usually starts increasing rapidly (as the obvious or easy-to-fix corrections are made) and then slows as the improvements become more difficult to implement. In its idealized form, this forms a smoothly rising curve (Figure 1).

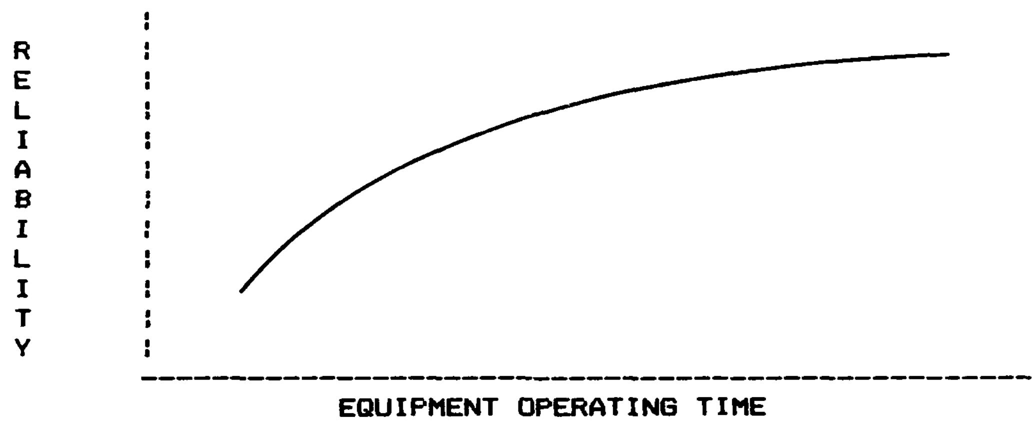


Figure 1

Idealized Growth Curve

The reliability does not actually grow in such a smooth fashion. Since improvements to hardware rarely occur uniformly, the curve will not be smooth. Often, the time between detecting a failure and modifying the hardware

causes delayed growth. At times, corrections will be added to equipment in batches causing the reliability to jump upward. The reliability growth is then seen as a series of rising curves with a separate curve for each phase (Figure 2).

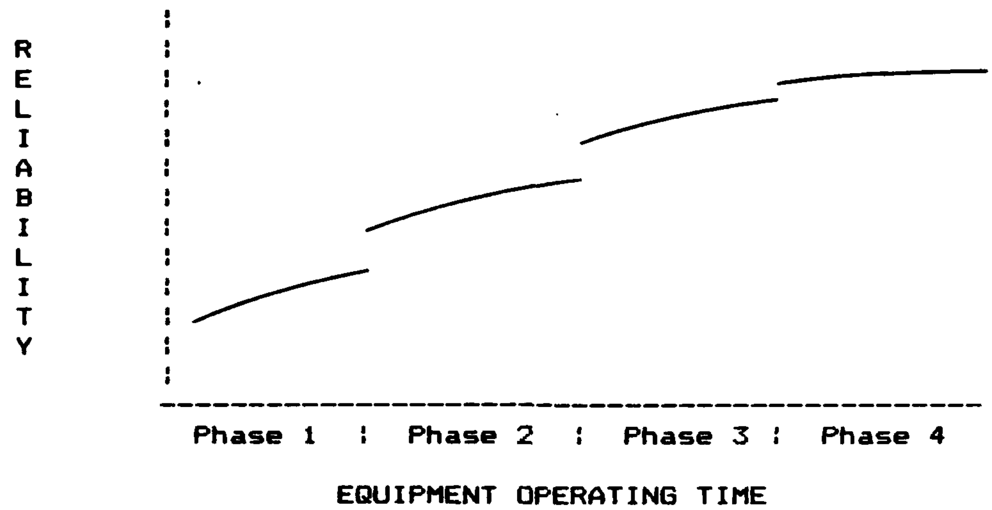


Figure 2

Phased Growth Curve

Even though the idealized curve is not accurate at all times during the program, it is very useful in quantifying the overall development effort and is a significant tool in the planning or monitoring of reliability growth (DOD 3235.1-H, 1982).

In 1962, J.T. Duane reported that cumulative

reliability growth curves approximated straight lines when plotted on log-log graph paper. Since then, log-log plotting of cumulative reliability has been used as an easy method of depicting reliability growth.

Three ideal growth curves are plotted on log-log scales in Figure 3. All the lines start at the same point, but have different slopes. Since the slope of the line is proportional to the rapidity of improvements made on the observed equipment, the slope can be used to quantify the intensity of a growth program: a 0.1 slope represents a low intensity program while a 0.6 slope depicts a very intense program, with 0.3 as average.

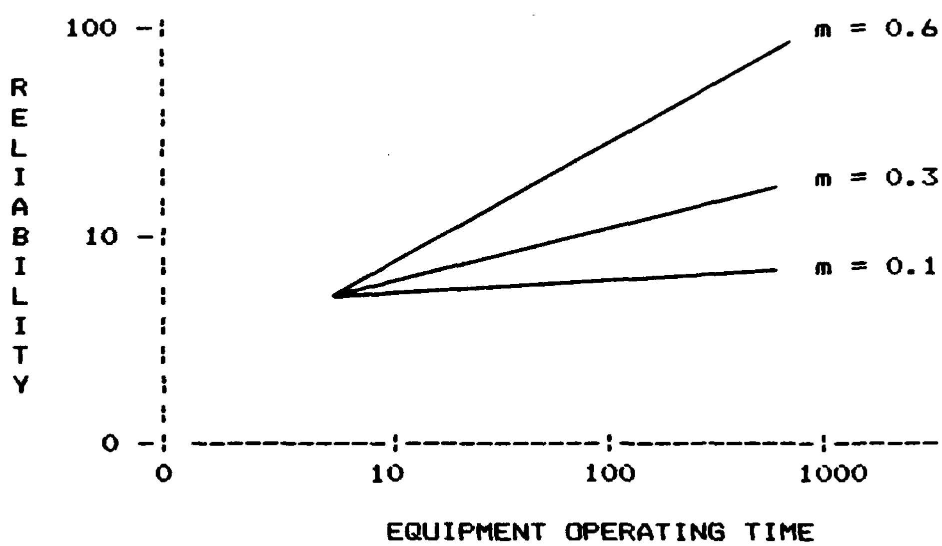


Figure 3

Log-Log Growth Curve

According to Codier (1968, p. 460):

> Where a systematic and deliberate reliability improvement effort is being made, [the slope] is usually found to be in the range 0.3 to 0.5. The value is . . . . higher in proportion to the . . . reliability improvement effort.

Reliability growth curves have several potential purposes. According to Anderson (1976, p. 27), they include:

1. Monitoring the reliability progress of the system as it proceeds through development.

2. Providing for the forecasting of short-term reliability.

3. Providing the means to measure the effectiveness of design changes.

4. Planning the development program and controlling its progress as the design matures.

All these can be used in managing the growth program.

Reliability Growth Management

Reliability growth management is the systematic planning for reliability achievement, and then controlling the rate of achievement by reallocating resources based on comparisons between planned and assessed reliability values (DOD MIL-HDBK-189, 1981).

Normally, the goal of a reliability program is to achieve the reliability and performance requirements. If the requirements are met by the initial equipment, no growth program is needed. But, as stated earlier, many systems do

not meet the reliability requirements by the end of their development programs. Sometimes the manager of a program has not been aware that the reliability requirements of the equipment were not being achieved until the end of the program when a final demonstration of the equipment was made and the reliability was lower than expected. Additional resources and time had to be allocated before the requirements were met.

Early emphasis on reliability performance can substantially increase the chance of meeting the objectives. Using reliability growth curves, the manager can assess the equipment's progress toward the reliability goals.

Department of Defense Directive (DODD) 5000.40 establishes policies and responsibilities for reliability and maintainability (R&M). In part, the reliability growth policy is:

> R&M growth is required during full scale development concurrent development and production . . . and during initial deployment. Predicted R&M growth shall be stated as a series of intermediate milestones, with associated goals and thresholds, for each of these phases (DODD 5000.40, 1980, p. 4).

A proposed handbook on reliability (DOD MIL-HDBK-XXX, 1982, p. 8-71) states:

> Reliability growth planning addresses program schedules, amount of testing, resources available and the realism of the test program in achieving the requirements . . . . It is, therefore, essential that periodic assessments of the reliability be made during the test

> program . . . and compared to the planned reliability growth values. By making appropriate decisions in regard to the timely incorporation of effective fixes into the system commensurate with attaining the milestones and requirements, management can control the growth process.

According to DOD MIL-HDBK-189 (1981), there are two ways that the manager evaluates the reliability growth process. The first is by assessing the quantitative reliability of the equipment throughout the program. The second is by a qualitative monitoring of the steps in the process to assure that they are accomplished in a timely manner and that the effort and quality of work comply with the program plan.

The assessment approach requires at least one quantitative evaluation of the equipment's reliability to match against the proposed growth curve. This is only possible after equipment has been built, and sufficient operation has taken place to develop a reliability value.

> The assessment approach is results oriented; however, the monitoring approach, which is activities oriented, is used to supplement the assessments and may have to be relied on entirely early in a program. This is often necessary because of the lack of sufficient objective information in the early program stages (DOD MIL-HDBK-189, 1981, p. 8).

It is important to remember that reliability growth management techniques do not, in themselves, manage. "They simply make reliability a more visible and manageable characteristic" (DOD MIL-HNBK-189, 1981, p.5).

Reliability Growth Programs

For the purposes of this paper, a reliability growth program is defined as any established program which results in the improvement of reliability through the five step process of:

1. Detection of failure sources,
2. Feedback of identified problems,
3. Redesign effort based on identified problems,
4. Building of improved hardware or software, and
5. Verification of improvements due to the redesign.

Since reliability growth can occur in hardware or software and results from correcting faults caused by design or workmanship, it follows that there may be no "one best way" to achieve the improvement. Any approach that follows the five step process should result in reliability growth.

The detection of failure sources usually occurs during the operation of the equipment. Since any operation can result in a failure, the detection of a failure can occur during both a formal testing program (with the failures reported in a test report) or during operation in the field (with failures reported by deficiency reports). The advantage of a formal testing program is that it results in many hours of operation under the close control of the testing agency.

The redesign of the hardware or software does not occur unless the program office and the contractor consider reliability growth necessary and allocate the time and funds to achieve it.

> Testing [by itself] does not improve reliability. Only corrective actions that prevent the recurrence of failures in the operational inventory actually improve reliability (DOD MIL-STD-785B, 1980, p. A-28).

The following chapters will present the current reliability growth programs of five major weapon systems under devlopment at ASD. The programs are the B-52 Offensive Avionics System, B-1B, F-15, F-16, and AGM-86B Air Launched Cruise Missile. Also presented will be a chapter describing the Component Improvement Programs for the engines used on the F-15, F-16, and the B-1B.

CHAPTER 3

B-52 OFFENSIVE AVIONICS SYSTEM

Background

The B-52 Offensive Avionics System (OAS) will replace a

> relatively low-reliability analog bombing and navigation system on B-52 G and H aircraft with high reliability solid-state digital equipment of greater accuracy and smaller size" (TASC, 1983, p. 1-1).

The OAS consists of 34 line replaceable units (LRUs) replacing 104 existing LRUs on each aircraft. The Strategic Air Command desired the update to "improve the system reliability and maintainability and to increase the navigation and bombing accuracies of the B-52 G&H" (ASD, 1978, p. 1).

The Strategic Systems System Program Office (SSSPO) of ASD is the directorate responsible for the development of the B-52 OAS. Development of the system started in 1978.

The prime contractor for the OAS is the Boeing Military Airplane Company (BMAC) who is responsible for installing the equipment in the aircraft and who also manufactures eight of the LRUs. There are six subcontractors who manufacture the rest of the OAS equipment.

Test, Analyze, and Fix Test

A subsystem Test, Analyze, and Fix (TAF) test was

conducted on selected OAS equipment by BMAC, and the subcontractors: Honeywell, IBM, Lear Seigler, Norden, Sperry, and Sundstrand. The test consisted of subjecting the equipment to a series of simultaneous vibration and rapid temperature cycles: conditions designed to accelerate failure rates. The test articles were operated and monitored for failure during the test using special test equipment. All failures were analyzed and corrective actions were formulated. The test was conducted in phases from July 1981 through October 1982 at the contractors' test facilities and cost approximately $15 million.

> The goal of TAF is the achievement of high reliability prior to the early delivery phase of production equipment. Enhancing reliability at this time is much less expensive than implementing reliability improvements by retrofit in fielded equipments (TASC, 1983, p. 1-2).

After identifying failure modes, the program office was to select certain corrective actions for implementation using cost/benefit analyses. The analyses took into account increased life-cycle costs and operational impacts if the corrections were not made. The contractors were not required to implement any corrective actions on their own, though some did so (at no cost to the Air Force).

The program office decided to forego any Reliability Improvement Warranty or Guaranteed MTBF (Mean Time Between Failure): proceeding with the TAF test instead. BMAC would have charged over $21 million in advance to allow for cor-

recting possible deficiencies under such a warranty or guarantee (ASD, 1978). The program office believed it could conduct a TAF test, identify any important reliability problems, and pay for the specific fixes while spending less than $21 million. In short, the reasoning was that the TAF test would save money.

Equipment Tested

Table 1 lists the equipment tested and the organization responsible for the testing.

Significant Test Requirements

Prior to starting the TAF test, the units must have passed their respective acceptance tests and been accepted by the Air Force or by the prime contractor.

During the test, each LRU type was to accumulate a total of 2400 hours of equipment operating time. Exception: IBM was to accumulate 600 cycles on the ACU regardless of the number of hours. To proportion the time between the test articles, each piece of equipment was to operate at least one half the average operating time of like equipment under test.

The test length (2400 total hours) was chosen to allow the completion of the test in time to incorporate the corrective actions in most of the production equipment. Unfortunately, due to delays, the first three lots of pro-

TEST ORGANIZATION	DESCRIPTION	NUMBER TESTED
BMAC	Armament Interface Unit	2
	Radar Interface Unit	2
	Electronics Interface Unit	2
	Controls/Displays Interface Unit	2
	Decoder Receiver	4
	Weapon Control Panel	2
	Radar Set Control	2
	Computer Subsystem Control Panel	2
Honeywell-Minneapolis	Electronic Altimeter Set, AN/APN-224	
	Receiver - Transmitter	2
	Height Indicator	2
IBM	Avionics Control Unit, APY-10 (ACU)	4
Lear-Seigler	Attitude-Heading Gyroscope Set, AN/ASN-134	
	Displacement Gyroscope	2
	Electronic Control Amplifier	2
Norden	Radar Set Group OY-731 ASQ-176	
	Receiver Transmitter-Modulator	2
	Ferrite Switch	2
Sperry Flight Systems	Control Display Set AN/ASQ-175	
	Signal Data Converter	2
	Video-Recorder	2
	Digital Computer	2
	Multifuction Display Indicator	4
	Integrated Keyboard	4
Sundstrand	Data Transfer Set, AN/ASD-7	
	Transmitter Control	2
	Magnetic Tape Transport	4
	Electrical Equipment Mounting Base	2

Table 1

Equipment Tested

(BMAC, 1982)

duction were completed prior to incorporating most of the corrective actions.

Test Results

Table 2 shows the results of the test. The low number of failures for Honeywell, IBM, and Lear Siegler can be attributed to mature equipment design. All three contractors have manufactured similar equipment before (TASC, 1983).

ORGANIZATION	TOTAL FAILURES	RELEVANT FAILURES	INCORPORATED FIXES	RECOMMENDED FOR INCORP
BMAC	129	100	63	10
Honeywell	11	4	4	0
IBM	19	12	1	0
Lear Seigler	12	10	3	0
Norden	50	41	7	11
Sperry	100	91	46	9
Sundstrand	165	141	53	17

Table 2

Test Results

(BMAC, 1982; TASC, 1983)

From the 299 relevant failures, over 105 corrective actions were incorporated into the production design prior to the end of the test at no cost to the government. The in-production changes were of three basic types: process, part, and quality control.

Process changes involve a revision of the manufacturing steps in order to eliminate a failure mechanism. Part changes include the replacement of parts with more reliable and/or better performing componets or the use of screening to eliminate degraded parts. Quality Control (QC) changes involve increased surveillence of workmanship problems or revisions to the quality inspection procedures. (TASC, 1983, p. 2-3)

Some design change failures were also incorporated in production. "Design changes are those that require a change to existing parts, drawings or documentation which carry a cost associated for the change" (TASC, 1983). Where the design change was already approved, the change was included with the "incorporated in production" failures.

An additional 26 corrective actions were recommended to the program office for incorporation. These failures all required design changes which meant getting SPO approval.

Each failure which resulted in a corrective action or proposed corrective action was analyzed to determine its effect on mission success. Eight failures were found to cause a mission failure by inhibiting the release of weapons, 31 had no effect, and the rest caused a partial degradation of mission success probability (from 1 to 12 1/2%).

Potential Cost Savings

In addition to the improved mission reliability, there is the possibility of logistics support cost savings when the necessary corrective actions are taken.

Since logistics support costs are particularly sen-

> sitive to fluctuations in Mean Time Between Failure (MTBF), the cost savings which can be realized by controlling this factor are quite significant (BMAC, 1982, p.32).

The composite MTBF for all the units under test was calculated by BMAC to be 13 hours. If all the possible corrective actions were successful, the MTBF would rise to 65 hours: a theoretical increase of 400% (BMAC, 1982).

The Analytic Sciences Corporation (TASC), under contract to the SSSPO, calculated an 82% improvement in MTBF using field data for Mean Flying Hours Between Maintenance (TASC, 1983). Again, this is a theoretical calculation.

Using the Air Logistics Center logistics support cost model, BMAC calculated a 15 year cost savings of $224,360,000 if all the corrective actions were incorporated and the reasons for failure were removed. Initial spares were included in this estimate.

> If the TAF recommended changes were not incorporated, the above costs would be incurred over the next 15 years in additional support costs (spares, maintenance, support equipment, training requirements, and management (BMAC, 1982).

The savings of $224 million is optimistic. It assumes the effective implementation of all the recommended corrective actions and the reduction in the number of spares required due to higher MTBFs.

TASC estimates the savings to be $37 million. The initial spares are excluded from their calculations because those units have already been purchased. Also not all the

recommended corrective actions will be incorporated by the Air Force. Therefore the savings are expected to be lower than the BMAC estimate (TASC, 1983).

With either estimate, the theoretical savings are greater than the cost of the test. Adding the savings from not paying for a RIW and MTBF guarantee, the TAF test saved at least $43 million in life cycle costs.

Unfortunately there is no easy way to assess how many of the proposed corrective actions really work. There are no planned verification of the corrections. Also, there are no tests that can be used for a before vs. after comparison. Therefore the theoretical costs will probably never be confirmed.

Chapter 4

B-1B

Background

The B-1B aircraft is the Air Force's new strategic bomber to replace the aging B-52. Outwardly, the aircraft closely follows the design of the original B-1 that was cancelled in 1977. Internally, several changes were made, including updating the electronics to meet the threats of the 1980s (Slenski, 1983).

The B-1B SPO at ASD is responsible for the development of the B-1B aircraft and its support equipment. The SPO is acting as the prime integrator for the following associate contractors: Rockwell - Air Vehicle, Boeing Military Airplane Company (BMAC)-Seattle - Offensive Avionics, and Eaton Industries-AIL Division (AIL) - Defensive Avionics. The Propulsion SPO is responsible for the development of the aircraft's General Electric engines (see the F101 Engine Component Improvement Program).

Reliability Growth Management

In 1982, the Strategic Air Command (SAC) stated a need for the B-1B to have an inherent mean-time-between-maintenance (MTBMi) of 1.0 hours with a MTBMi goal of 2.0 hours. SAC also asked for a mission completion success probability (MCSP) of 0.92 for a hypothetical model mission

(Slenski, 1983).

> MCSP is defined as the probability that the aircraft shall complete the scheduled mission without experiencing an on-equipment failure or performance degradation which would result in an abort, or mission deviation which would preclude the accomplishment of the scheduled mission (ASD, 1981a).

The B-1B Test and Evaluation Master Plan (TEMP) has established the following thresholds and goals for MTBMi and MCSP at Initial Operational Capability (IOC) and maturity (200,000 flight hours):

	IOC	MATURITY	
	Thres	Thres	Goal
MTBMi (hours)	.25-.28	1.0	2.0
MCSP	.78	0.92	

In order to meet the above reliability requirements and to provide for the tracking of reliability improvements, the SPO has established reliability growth curves for each of the associate contractors. The curves are shown in Figures 4, 5, and 6.

The curves are plotted against log-log scales and are shown as straight lines. Each curve starts with a 0.3 slope and then changes to a 0.1 slope at IOC + 2 years (estimated to be 50,000 flight hours). The curves continue up to maturity at 200,000 flight hours.

Test, Analyze, and Fix Test

A Test, Analyze, and Fix (TAF) test is planned for the avionics procured from Rockwell, AIL, and BMAC. The B-1B

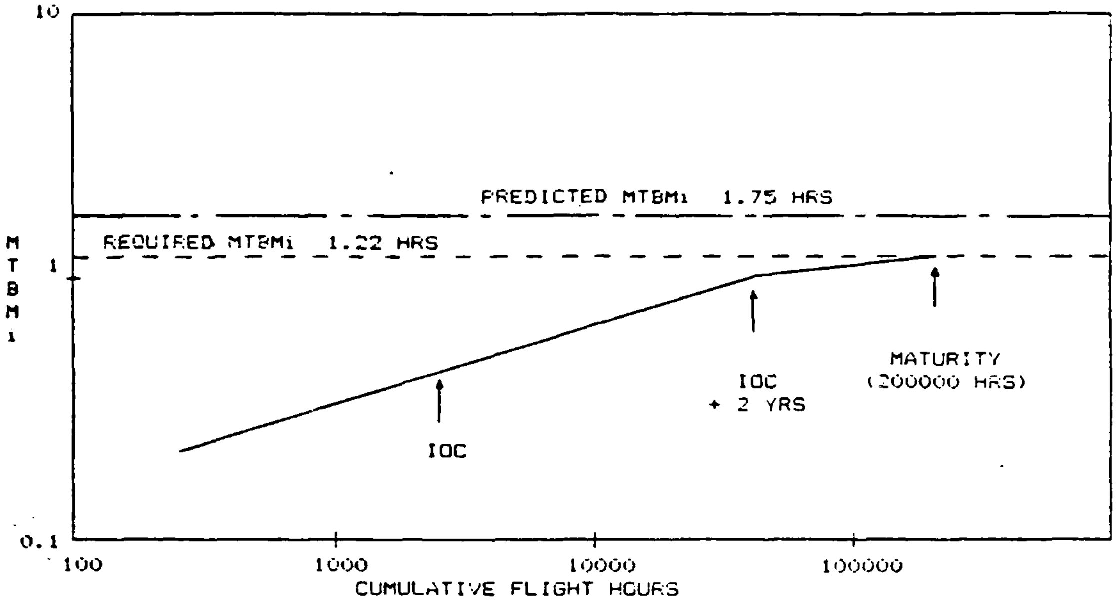


Figure 4

B-1B Aircraft

(Slenski, 1983)

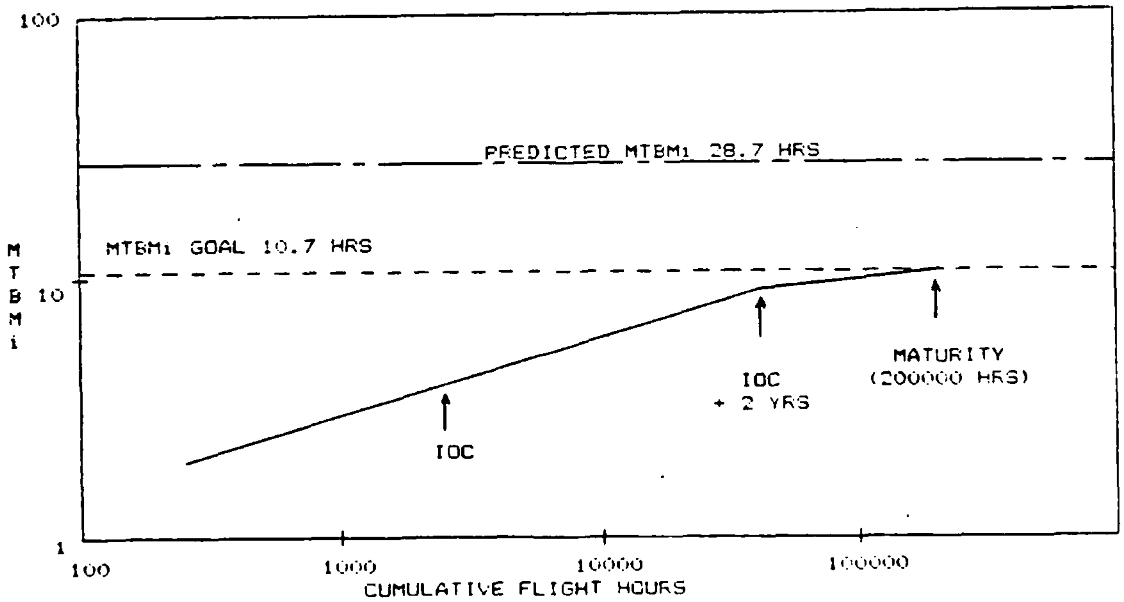


Figure 5

Boeing Avionics

(Slenski, 1983)

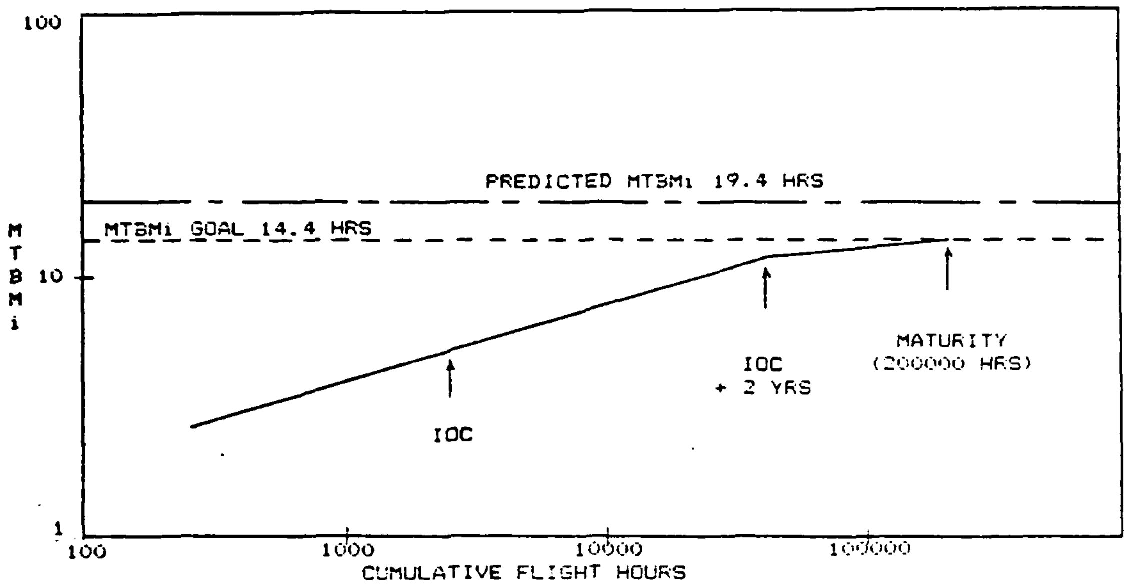


Figure 6

AIL Avionics

(Slenski, 1983)

SPO believes the TAF test is needed to achieve the required reliability and is not intended to correct known reliability problems (Slenski, 1983).

The test will consist of rapid temperature cycling with simultaneous random vibration. The performance of the equipment will be checked at intervals during the test. The test, starting in 1984, will accrue 1000-2000 total hours of operation for each equipment type. Rockwell will test at least two of each type of equipment (each equipment under test will accumulate at least 500 hours of test time). BMAC will test two of each type of equipment (with a 250 hour minimum) and AIL will test at least one of each type (Slenski, 1983).

The test lengths were chosen as a compromise of three things: the need to obtain growth, have failure verification, and be affordable. The tests had to be long enough that some correctable failures are likely to be found. Then, additional test time was desired to verify that the implemented corrective action worked as intended. Finally, since the entire test had to be affordable, the proposed tests were held to 2000 hours or less for each equipment type.

Any failures during the test will be analyzed down to the piece part level by the contractor, the failure mechanism will be identified, and a corrective action recommended. As in the OAS TAF test, the contractors are not required to incorporate any corrective actions by themselves. As in the OAS TAF test, the contractors may incorporate corrective actions at no cost to the government. The B-1B SPO will review the recommended corrective actions and then implement and fund corrections using ECPs.

There are no direct costs or savings identified for this program. The TAF test is included under the broad Work Breakdown Structure of "Reliability" and is not priced separately. Therefore the actual cost (after contract negotiations) is unavailable.

Because the TAF test is early in the program, there

can be no actual before/after comparisons of achieved reliability. At the conclusion of the test, a theoretical estimate of the improvements can be made using test data.

Since the B-1B TAF test was patterned after the B-52 OAS TAF test, similar results can be expected. The test should identify many failures that can be corrected by the contractor at no cost to the government. A few major corrections will need additional funds to implement, but the savings should outweigh the costs. The total saving probably will not be as great as for the B-52 OAS because there will be fewer units produced (for 100 B-1Bs vs. over 200 B-52s).

Chapter 5

F-15 EAGLE

Background

The F-15 Eagle is the USAF's primary air superiority fighter. Designed and built by McDonnell Aircraft Company, the F-15 first flew in 1972. By the 1990s, the USAF intends to buy over 1,470 of these fighters. A current effort by the Directorate for Tactical Systems is to upgrade the avionics to make the equipment more flexible.

Multi-Stage Improvement Program

The Multi-Stage Improvement Program (MSIP) is intended to update the capabilities of the F-15 to "keep place with technology" and provide a "viable weapon system into the 1990s" (Roadruck, 1983). The major improvements include:

Programmable Armament Control System (PACS)
Improved Central Computer (CC)
Improved air-to-ground radar

"Multi-stage" refers to the phased schedule of incorporating the improvements into the fleet of F-15s.

While reliability improvement is not the main goal of the MSIP, certain MSIP equipment will undergo a Reliability Development Test (RDT) which should result in reliability growth. The tests will be conducted at the

contractors plants using environmental chambers. The tests are intended to identify high risk failure items which impact reliability.

The reliability growth objectives of the RDT are:

> to grow the reliability of the equipment by systematic identification and elimination of failure causes by formulation of effective corrective action for <u>each</u> [emphasis added] failure encountered during the test (without regard to relevancy of failure) (Edwards, 1983).

The following production (or preproduction) equipment will undergo RDTs:

EQUIPMENT	CONTRACTOR
Multipurpose Color Display (MPCD)	Sperry
Programmable Armament Control Set (PACS)	Dynamics Control
Central Computer (Modified) (CC)	IBM
Improved Radar	Hughes

Table 3 shows the specified and predicted mean times between failure, the number of units, and the total operating hours for each type of equipment in the test.

EQUIPMENT	SPECIFIED MTBF (hrs)	PREDICTED MTBF (hrs)	TEST HOURS	UNITS TO BE TESTED
MPCD	500	2500	5000	2
PACS	400	395	4000	2
CC	1200	1500	6000	3
RADAR	75	169	500	1

Table 3

Reliability Demonstration Test Requirements

(Harmsworth, 1983)

> The tests are structured to identify high risk failure items which, if uncorrected, would cause the equipment to exhibit unacceptable levels of reliability during operational usage (Tactical Systems, undated, p. 1).

The program office has reserved the right to terminate the test at any time if the objectives are not being met (e.g. if there are no failures) (Harmsworth, 1983).

The test lengths were proposed by the prime contractor, McDonnell-Douglas. The program office requested a growth test length at least five times the specified MTBF as recommended in MIL-STD-1635 (EC). McDonnell-Douglas responded with proposed tests between five to ten times the specified MTBF as shown in Table 3 (Edwards, 1983).

Each test sample will have completed burn-in (environmental stress screening to remove early failures) and acceptance testing before starting the RDT. Reliability qualification tests will take place after the RDT.

The RDTs will consist of rapid temperature cycling combined with random vibration and induced humidity. The performance of the equipment under test will be measured on a routine basis using built-in-test (if available) and periodic acceptance tests.

If a failure occurs, the equipment will be repaired, re-pass an acceptance test, and be returned to the RDT. While the equipment is being repaired, a spare

shop-replacable- unit will be used as a replacement to allow the test to continue. A failure analysis will be performed on each failure and a corrective action will be formulated.

Using theoretical values proposed by Duane (1962), Harmsworth (1983) plotted growth curves for the MPCD, PACS, and CC (Figures 7, 8, and 9). To achieve the required reliability in the planned hours of test operation, the slopes of the improvement plots need to be 0.3, 0.35, and 0.6 respectively.

While a growth program requiring a improvement slope of 0.6 is possible, such a program is ambitious. According to Codier (1968), the normal range of expected slopes are from 0.1 to 0.5. Normally, achieving a 0.6 slope will require correction of every failure regardless of the time or money involved in formulating or implementing the corrective action (General Electric, 1973). Resource constraints would probably restrict the growth program, resulting in a lower slope.

Edwards (1983) believes the actual MTBF of the Central Computer as it enters the growth test will be higher than the value predicted by Harmsworth using Duane's theory. Edwards believes the computer's MTBF will be higher because the B-1B is using a similar computer and the F-15 program should benefit from the testing done by the B-1B program.

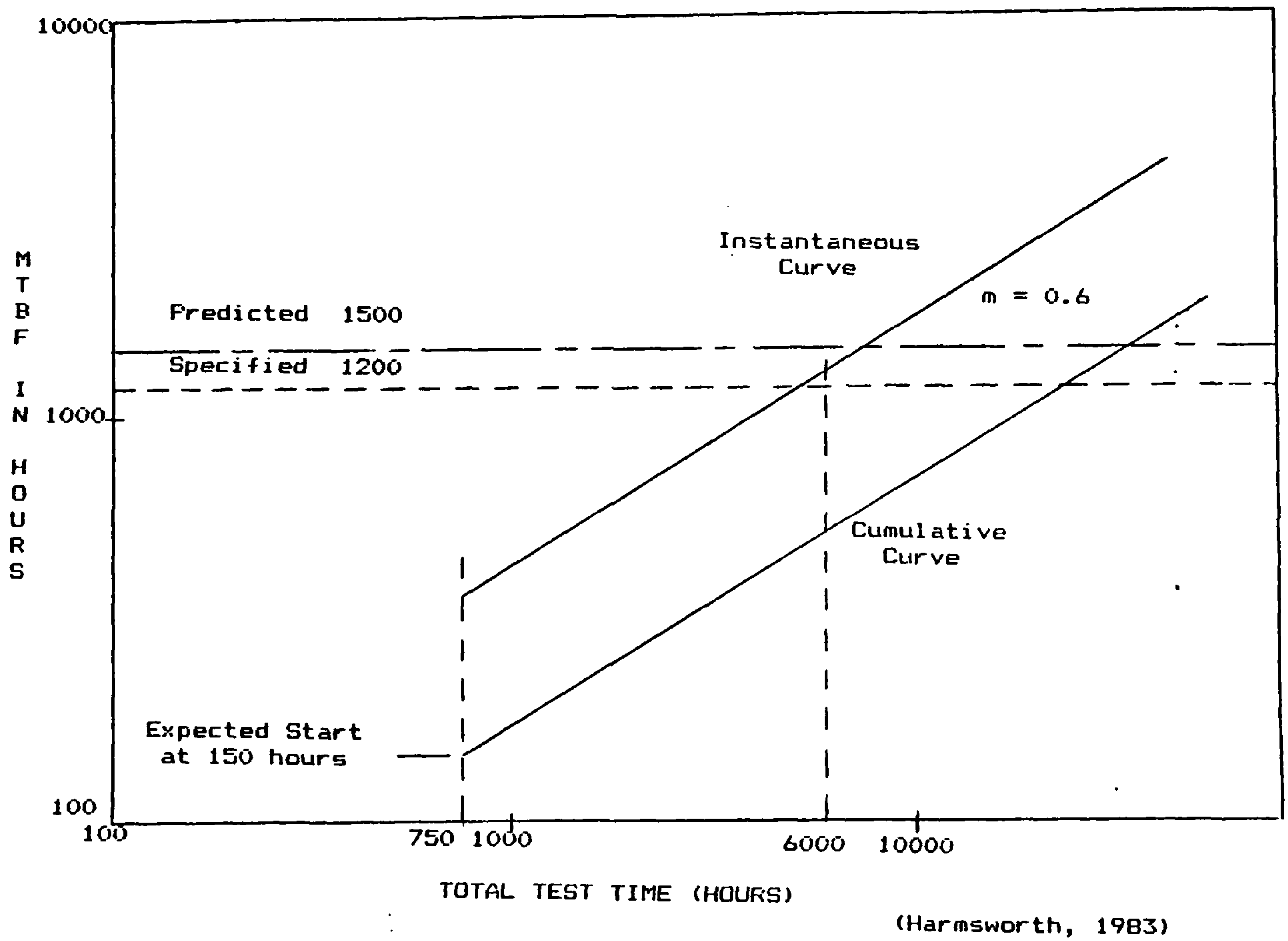
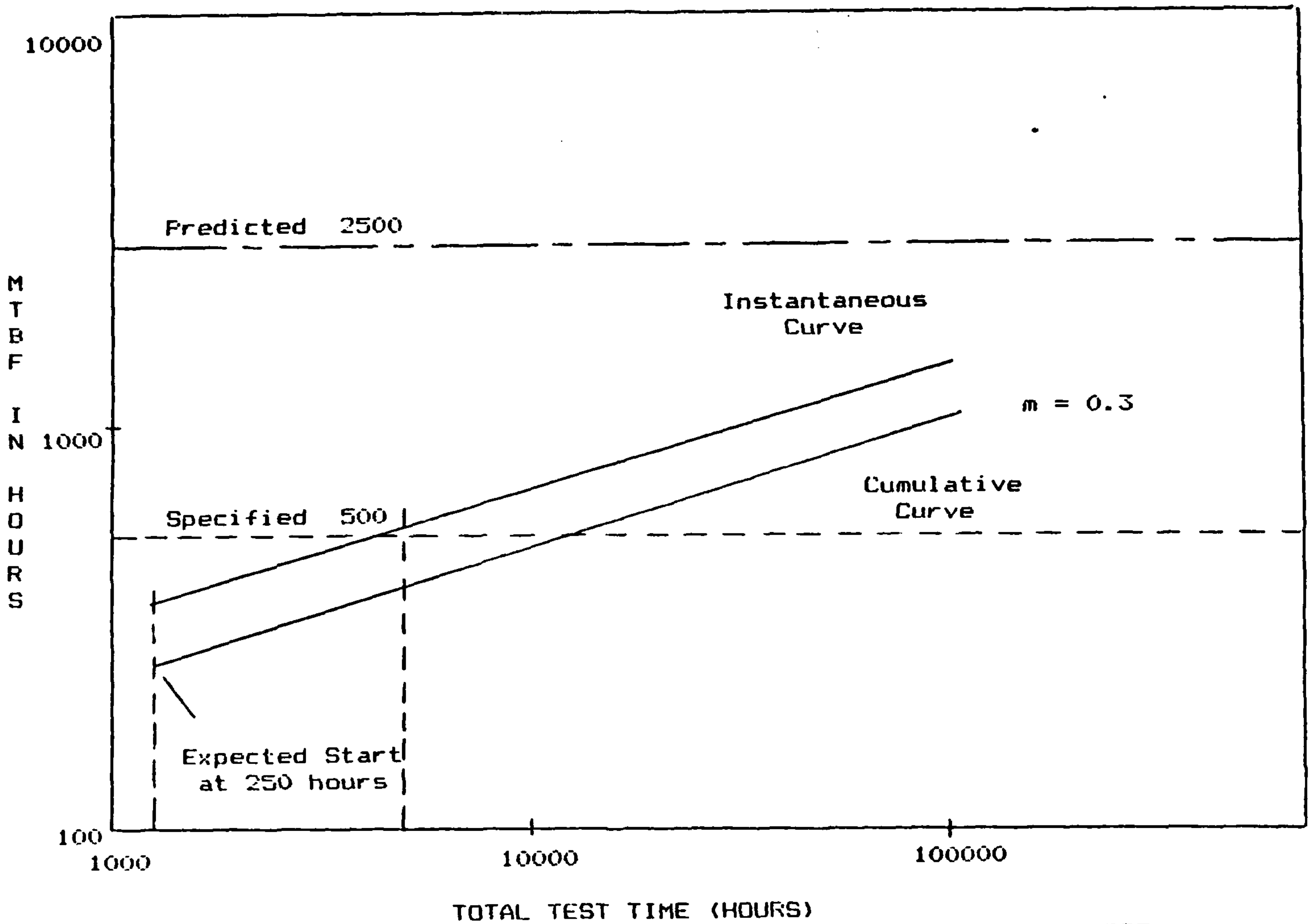
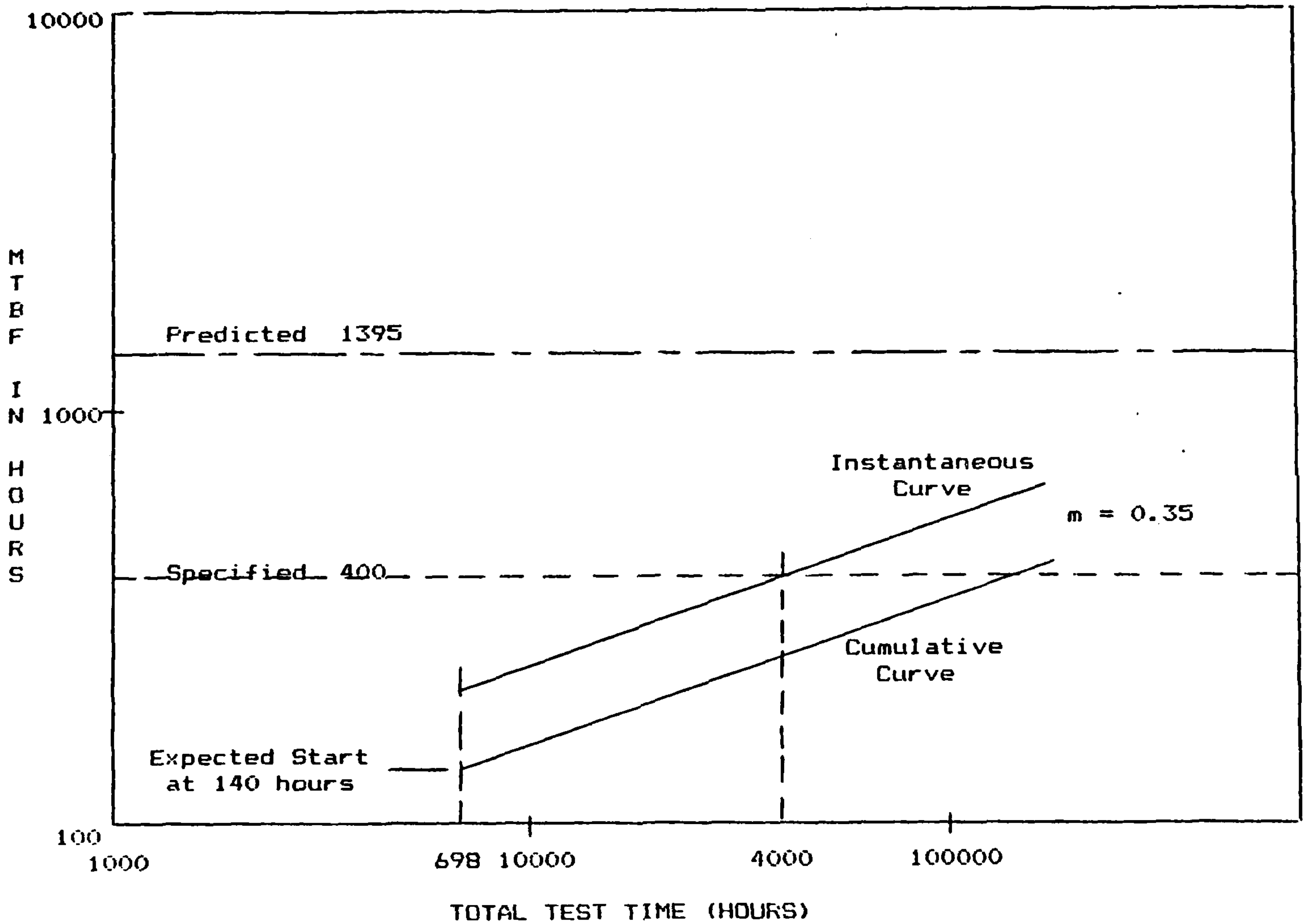


Figure 7. Central Computer Model



(Harmsworth, 1983)

Figure 8. MPCD Model



(Harmsworth, 1983)

Figure 9. FACS Model

CHAPTER 6

F-16 FIGHTING FALCON

Background

The F-16 was designed by General Dynamics as a replacement for the F-4. The first F-16 entered the active force in 1979 with total procurement scheduled to be 2,165 aircraft by 1985. As with the F-15, the current effort is to update the technology of the avionics in the aircraft.

Multinational Staged Improvement Program

The Air Force instituted a Multinational Staged Improvement Program (MSIP) on the F-16 in 1980. This on going program increases the capabilities of existing avionics and makes provisions to accept future systems, therefore reducing retrofit costs. The update of the existing equipment is being performed by General Dynamics.

The updated equipment design will have to pass three reliability demonstration tests before being accepted by the Air Force: a Development Reliability Test (DRT), a Production Reliability Qualification Test (PRQT), and a Production Reliability Acceptance Test (PRAT).

The DRT will be performed on preproduction equipment and the PRQT will be performed on production equipment. The

tests are conducted on behalf of the government to demonstrate compliance with the reliability requirements as a basis for production approval. The PRAT is performed on delivered production units to determine compliance with the reliability requirements.

The reliability requirements increase as the design goes through the tests. The preproduction equipment has a lower mean-time-between-failure (MTBF) requirement during the Development Reliability Test than the production equipment has during the PRQT and PRAT. The equipment, the required MTBFs, and the test type are shown on Table 4.

EQUIPMENT	REQUIRED MTBF DRT	PRQT & PRAT	TEST TYPE
Fire Control Computer	200	500	Sequential
Multi-Function Display Set	95	320	"
Central Interface Unit	85	250	"
Data Entry Electronics Unit	350	900	"
Data Transfer Unit	2000	4000	25 hours of failure free operation

Table 4

F-16 MSIP Reliability Requirements

(ASD, 1981b)

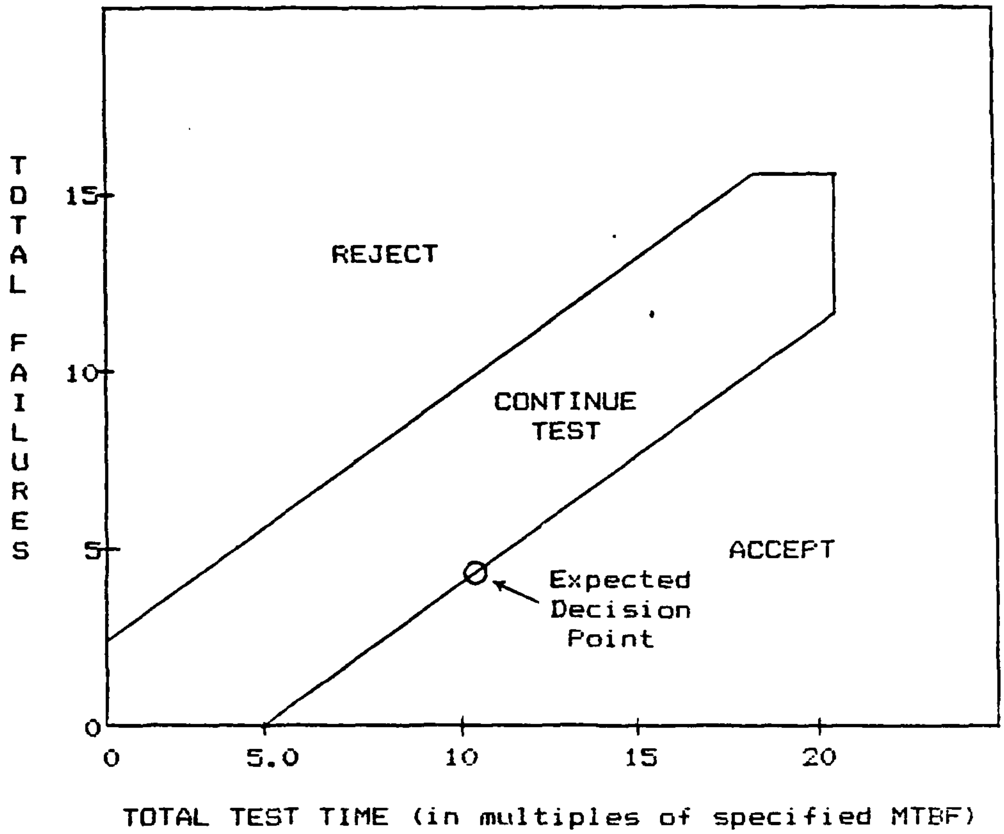
The Development Reliability Test will be conducted on two pre-production units of each type. The Reliability Qualification Test will use five units of the first 50 units delivered and the Production Acceptance Test will be

conducted on eight units of the next 100 produced. The Air Force will randomly select the units to be tested.

Sequential tests may be used to accept or reject predetermined MTBF values when the total test time is relatively unimportant (DOD MIL-STD-781C, 1977). During a sequential test the cumulative operating test time is plotted on a graph similar to Figure 10. The reject line and the boundary line are drawn on the graph prior to the test. If the plot crosses the reject line, the test is stopped, and the contractor must submit a corrective action plan and incorporate the corrective actions prior to attempting the test again. The corrective actions and the retest are all paid for by the contractor. If the test is completed before the plot crosses the reject line, the equipment passes the test and no corrective action is required for any failures seen.

A sequential test is not performed on the Data Transfer Unit because of the large number of hours required to demonstrate its high MTBF during such a test. Instead it will have to operate without a failure for 25 hours to pass its reliability tests. If a failure occurs, the failure will have to be analyzed and corrected before another unit may attempt to pass the test.

Gary Arnold, Reliability Engineer for the MSIP, believes the high cost of failing the tests will cause the



(DOD MIL-STD-781C, 1977, p. 82)

Figure 10. Accept-Reject Criteria for Sequential Test

contractor to carefully design and manufacture the equipment, making a reliability growth program unnecessary. Also, since the FRQT and the FRAT have higher MTBF requirements than the DRT (except for the Data Transfer Unit), the most important failure modes found during the Development Test will be corrected by the contractor prior to the start of the Production Tests (Arnold, 1983). If the correction of failures occurs, the result is a reliability

growth program by the contractor.

Improved Radar Reliability Achievement Program

The F-16 SPO is also increasing the capabilities of the AN/APG-66 radar used on the F-16. The approach used is similar to that used on the MSIP except a Reliability Growth Test is planned in addition to the development and production reliability tests. The test requirements are shown in Table 5.

TEST	NUMBER OF SYSTEMS	REQUIRED MTBF (hrs)
Reliability Qualification	2	25
Production Rel Qualification	5 of 75	35
Production Rel Acceptance	5 of 200	35
Reliability Growth	7	750 operating test hours

Table 5

F-16 Improved Radar Reliability Requirements

(Anderson, 1983)

Westinghouse predicts the slope of the Improved Radar reliability growth plot to be 0.4. Since reliability growth testing just started in August 1983, there is not enough data to compare to the predicted plot, but a growth of 0.4 is achievable for a radar system (Codier, 1968 and General Electric, 1973).

CHAPTER 7

COMPONENT IMPROVEMENT PROGRAMS

This chapter describes the Component Improvement Programs for the turbine engines used on the F-15, F-16, and B-1B aircraft.

Background

Engines developed for new bombers and fighters normally use the latest technology and can be described as being the state of the art.

> Much time, money, and effort is expended in pulling together past and present knowledge to produce an engine with specified characteristics. . . . It will contain many compromises because it must have many characteristics, some of which are diametrically opposed to others (ASDP 800-21, 1979, p. 21).

When a engine fails to meet a given standard, the original compromises have to be reevaluated in light of the new knowledge available.

> The Component Improvement Program [(CIP)] is a contractual engineering service, normally done by the original manufacturer and includes testing, analysis, and ECP submittals. CIP is the vehicle used to transfer this new knowledge to engine hardware (ASDP 800-21, 1979, pp. 21-22).

During development, new engines are pushed to the threshold of technology and hardware limits. Sometime those limits have been exceeded requiring corrective actions.

The government should accept . . . the fact that

development programs are risky at best, the outcome cannot be accurately predicted in advance, and early operational problems are to be expected and overcome (ASDP 800-21, 1979, p. 17).

According to Smith (1983), Product Assurance Focal Point in the Propulsion SPO, reliability growth of jet engines is approached differently than the improvement of electronics. Three factors explain the different approach: availability of test cells, the cost of testing, and aging of equipment.

Engine qualification requires the use of government test cells that can be used to simulate various flight conditions. These cells must have provisions for air flow, altitude simulation, and temperature variation. There are only three government facilities available for performing tests: Arnold Engineering Development Center (AEDC), Naval Air Propulsion Center (NAPC), and NASA/Lewis Research Center.

The productivity of the cells limits availability. Because of the limited number of testing sites, various jet engine development programs compete for test cell time. Engines must be scheduled for the cells months in advance. Unlike environmental chambers for electronic equipment which can operate over 100 hours per week, engine test cells average only 30 hours of operation (Smith, 1983).

Cost is a major factor in jet engine testing. Due to the low productivity (which determines how much overhead

is charged to each test hour) and the high energy costs to operate the test cells, testing costs approximately $10,000 per operating hour. Thus, testing can absorb much of the budget for engine development.

Also unlike solid state electronics, jet engine parts age or wear out during use. Testing is required to identify the point of wear out. Unfortunately, many parts do not reach their wear out points during the limited amount of testing performed during initial development. Therefore, the parts do not wear out until after the engine is installed in an aircraft and flight testing takes place.

Thus, a new jet engine is not ready for operational use when it is released for flight testing. In fact, because of the factors listed above, the engine may have less development testing than any other piece of equipment on the aircraft. Often the engine enters flight test without demonstration of many of the reliability/durability requirements. Knowing this, the Propulsion SPO uses Component Improvement Programs to correct reliability deficiencies and to improve the engine above the demonstrated reliability.

CIPs are used to resolve operational problems with gas turbine engines in as short a time as possible after development. The CIP begins with the successful completion of full scale engineering development and continues

throughout the useful life of the program (AFR 800-30, 1980).

AFR 800-30 (1980) establishes the requirement for a CIP and requires a program to have:

1. Accelerated mission testing of the production model.

2. Ground testing of production and overhauled engines to allow comparison to base-line characteristics.

The regulation goes on to state that the CIP will:

1. Resolve technical, operational, and support problems discovered in use by the user;

2. Achive the durability and reliability specified in the contract . . . .

3. Assess changes in mission requirements for impact to reliability and durability (AFR 800-30, 1980, p. 3)

The regulation specifically excludes actions that improve the engine above specification performance values "unless the improvement will resolve a user's durability or support problem" (AFR 800-30, p. 3). Additional improvements that improve performance and durability above specification values belong to the Engine Model Derivative Program which is outside the scope of this paper.

CIPs are intended to find problems to correct. Once possible improvements are identified and evaluated, ECPs are used to implement proposed corrective actions. CIPs do not pay for the incorporation of fixes in the production line or into the fleet of aircraft in the field.

F100 Engine CIP

The F100 engine, manufactured by Pratt & Whitney Aircraft (PWA), powers both the F-15 (F100-PW-100) and F-16 (F100-PW-200) aircraft. Development of the engine began in 1968, with the first flight in a F-15 in 1972. The Component Improvement Program on the F100 engine started the following year with an $106 million contract with PWA.

Since 1973 the Air Force has spent over $670 million ($ FY82) on the F100 CIP. While that seems like a lot of money, the Propulsion SPO estimates the life cycle cost savings from approved improvements to be over $3.6 billion ($ FY 82). The reliability improvements are included in the costs and benefits and are not available separately (Furgeson, 1983).

Several measures of reliability merit are tracked by the Propulsion SPO for the F100 engine. They are:

1. Mean Time Between Hardware Failure (MTBHF). The mean engine flying hours (EFH) between hardware failures. Includes all unscheduled maintenance involving replacement or repair of an engine part at base level.

2. Unscheduled Engine Removals per 1000 EFH. Includes all base level removal caused by engine hardware failures plus all one time time-change Technical Order directed inspection removals.

3. Class A Mishaps per 100,000 EFH. Class A Mishaps are defined by AFR 127.4 [sic] to be those mishaps resulting in a total cost $500,000 or more for injury, -cupational illness and property damage; a fatality or permanent total disability; destruction of or damage beyond

economical repair to an Air Force aircraft.

4. Non-Recoverable In-Flight Shutdown per 100,000 EFH. Includes all engine chargeable incidents that caused a non-pilot elected shutdown of the engine where a restart was unsuccessful (Furgeson, 1983).

Table 6 shows the change in the reliability measures since 1981.

MEASURE OF RELIABILITY		DEC 81	DEC 82	JUN 83
Class A Mishaps per 100,000 EFH	(F-16)	5.63	3.65	2.67
Unscheduled Engine Removals per 100,000 EFH	(F-15)	5.36	4.87	4.64
	(F-16)	4.17	4.04	3.72
Mean Time Between Hardware Failure	(F-15)	34.6	37.4	42.8
	(F-16)	38.3	39.8	41.5
Non-Recoverable In-Flight Shutdown per 100,000 EFH	(F-15)	10.6	8.0	6.2

Table 6

Change in F100 Engine Reliability Measures

(Furgeson, 1983)

The reliability improvement caused by the CIP on the F100 engine is apparent from these numbers.

F101-GE-102 CIP

The F101-GE-102 engine, built by General Electric, is used in the B-1B bomber. The engine has a design life goal of 10,000 hours with parts exposed to the hot gas stream in the engine having a 3,000 hour design life goal (Scully, 1983).

The CIP for the F101-GE-102 engine is planned to

start in FY84 and is programmed over four years. General Electric has proposed spending $187 million for the testing of engines and the identification of possible improvements. The tests will provide information about the life of engine parts, and engine performance, durability, reliability, and maintainability. Of the $187 million, $124 million is proposed for life verification, durability improvements detected during full-scale development (FSD), and reliability and durability enhancements (Williams, 1983)

Funding constraints will limit GE's proposed program. For example, GE proposed $53 million for the CIP in 1984 while the Propulsion SPO has budgeted only $40 million. Negotiations are underway to redefine the CIP for FY84 (Williams, 1983).

The CIP for the F101 engine is very similar to the CIP for the F100 engine. Costs should be about the same for testing and engineering, but the savings on the F101 will be lower because of the smaller number of engines and aircraft affected by the improvements.

CHAPTER 8

AGM-86B AIR LAUNCHED CRUISE MISSILE

Background

The AGM-86B Air Launched Cruise Missile (ALCM) is a small, unmanned, winged air vehicle capable of sustained flight following launch from a carrier aircraft. The nuclear-armed missile is currently deployed with B-52G aircraft and may be carried on B-52H and B-1B aircraft.

Development of the AGM-86B ALCM was started in 1976 with Boeing Aircraft Company (BAC) as the airframe and integration contractor. McDonnell-Douglas Aerospace Company (MDAC) provided the navigation/guidance system and Williams Research (now Williams International) provided the propulsion system as associate contractors.

In 1980 the AGM-86B won a fly-off competition against the AGM-109 designed by General Dynamics. The competition consisted of ten flights for each missile and several maintenance demonstrations.

Due to the size and weight restrictions of the missile, very little redundancy was built into the on-board systems. Because of this, almost any failure would result in the loss of the missile. Recognizing the criticality of failures, the designers planned for the use of high

reliability parts and severe qualification tests (including failure free combined environment tests for the electronic and electro-mechanical equipment) to achieve a high initial reliability.

Because of the intense design and demonstration testing, no formal reliability growth tests were planned for the ALCM. It was thought that the few improvements needed would be highlighted by the flight test program. Unfortunately the system did not perform as well as expected when flown. For example, the first flight crashed due to a software parameter value error.

The operation of the missile during the flight test program did highlight errors that needed to be corrected before the missile could be used as a strategic nuclear weapon. By June 1983, seven out of 32 test flights ended in failure. Without a formal reliability growth program, improvements were made using the Material Deficiency Reporting and Investigating System (see Appendix A.)

The first service report was received in July 1979. Since then, 854 service reports have been submitted on the ALCM and its support equipment. Of those, 48 were reliability/ maintainability related (Fowler, 1983).

Reliability growth of the ALCM was assumed from the start. Changes were programmed for the cruise missile program, based on deficiencies discovered during all phases

of flight testing. Thresholds and goals (derived using Duane's theoretical growth model) were established for the system and were used to monitor the progress of the missile's reliability throughout its development and initial deployment.

The 1980 Decision Coordinating Paper (DCP) for Milestone III (decision to enter production) set model -mission reliablity thresholds at the end of the competitive flight test program and at the end of development. A reliability goal at maturity (December 1984) was also established. The model mission included 45 days of ground alert (attached to a B-52), 12 hours of being carried in flight by the B-52 prior to launch, and then a five hour free-flight to the target. The DCP thresholds and goals were:

	Competition	Development	Maturity
Air Vehicle Reliability	0.575	0.86	0.88

The Secretary of Defense Decision Memorandum (SDDM) on the ALCM (1980) established a threshold and goal for the combined B-52/ALCM system. The SDDM called for the reporting of the Alert Availability for the entire system at First Alert Capability (Oct 1981), Initial Operational Capability (Dec 1982), and maturity (Dec 1984). The SDDM goals and thresholds were:

	FAC	IOC	MATURITY
Alert System Availability	0.87	0.90	0.93

Based on flight tests, the air vehicle reliability was 0.78 at the end of competition, 0.79 at FAC, 0.80 at IOC, and 0.78 at the end of development (Campbell, 1982).

Due to the small sample size and low number of flight tests, the apparent lack of growth since the end of competition cannot be confirmed. Corrective actions have been taken to remove failure modes and those actions were adequate: no repeated failures occurred. Unfortunately new failure modes appeared at the same rate that the old failure modes were corrected. As a result, there was no change in the reliability.

CHAPTER 9

SUMMARY AND CONCLUSIONS

Summary

The approaches taken by the system program offices to achieve reliability growth are varied. At one extreme, there is a lack of formal reliability growth programs (AGM-86B and F-16 MSIP). The expectation on those programs was that the design is adequate or that improvements will result from development and production testing. A formal reliability growth program was considered unnecessary.

At the other extreme are the planned reliability growth tests as part of the original program (B-1B, F-16 Improved Radar, and F-15 MSIP). On those programs, the approach was to assume from the start that the initial reliability needed to be improved to achieve its required level.

In between the two extremes is the Test, Analyse, and Fix test of the B-52 OAS. There, a formal TAF test was used to improve the reliability after the first production units were already built. The intent was to reduce the risk of having poor reliability and also to lower life-cycle costs.

It is difficult to assess the success of the

reliability growth programs because the data to do such an analysis is seldom available. Most programs normally rely on the field data tracking directed by AFR 66-1 (B-52 OAS, B-1B, F-15, F-16). Unfortunately, the compiled data made available by AFLC is not accurate and discriminating enough to assess the impact of reliability growth.

The programs that do track improvements through other means often combine the results from reliability oriented improvements with those from manufacturing and cost savings programs. The total result of all the corrections is tracked, but after an individual correction is made, the separate tracking of its result is lost.

Conclusions

There does not seem to be a consensus on the "one best way" to achieve reliability growth. The managers and engineers of the system program offices use the methods that are they expect to work for them.

A big question is: how to know what type of program to specify? If there has been a growth program on similar equipment by the same contractor, some of the unknowns are removed. The experience of either the SPO or the contractor can be helpful in determining test length, sample size, and other factors. Otherwise, unknowns about cost, schedule, and numbers of equipment to be tested all can impact on a growth program usually by raising cost and lengthening

schedules.

The contractors are important to a successful growth program because they do the testing and assume some of the risks. If the contractor considers the risks to be high, the price of the growth tests will increase considerably, but these risks could be reduced if the contractor has had previous experience and the test is fixed length.

A fixed-length test removes the risk of an abnormally long test consuming unplanned time and money. For example, during the sequential tests used on the F-16 MSIP, the actual test length could vary from 2.8 to 9.74 times the required MTBFs. Thus, during the Production Reliability Qualification Test on the fire control computer, the test time could vary from 1400 to 4870 hours (DOD MIL-STD 781C, 1977). To limit the risk, the contractor priced the contract for the maximum test hours.

If neither the SPO nor the contractor has experience to draw from, the task of specifying the program requirements will be difficult. For example, it will be necessary for the SPO to educate the contractors so they understand the requirements and the intent of the specifications. Neither the SPO nor the contractors may know how to perform the five step reliability growth process to achieve the desired improvements.

Also, the contractors may not know what level of

effort is required to analyze failures and incorporate the necessary corrective actions. In this case it will be necessary for the SPO and the contractor to work together using the experimental knowledge they collect to adjust the program as required. All the uncertainties create risks, and the risks endanger a successful, on time reliability growth program.

A meaningful comparison of reliability growth techniques is not possible based on the data available from traditional sources. Useful data is not available to allow comparisons between different programs. To gain the necessary insights, a separate, more detailed data system needs to be created.

APPENDIX A

USAF MATERIAL DEFICIENCY REPORTING AND INVESTIGATING SYSTEM

One way for ASD managers and engineers to improve the reliability of existing equipment is to actively use the USAF Material Deficiency Reporting and Investigating System of Technical Manual TO 00-35D-54.

The Product Improvement Policy (PIP) for the Air Force is outlined in AFR 66-30. A PIP for a specific product starts as soon as possible after the first item is accepted by the operating command, a production decision is made, or when operational test and evaluation (OT&E) begins (AFR 66-30, 1982, p. 1).

An objective of the policy is to "prevent the recurrence of deficiencies in design" in order to improve the cost-effectiveness and readiness of equipment in the Air Force inventory (AFR 66-30, 1982, p. 1). The regulation outlines the following steps to achieve improvement:

1. Review the operation of equipment in the field or in OT&E for adequate reliability.

2. Analyze systems with marginal or unsatisfactory performance to identify the nature and cause of the deficiency.

3. Identify possible corrective actions.

4. Use the results of the improvement efforts to keep the deficiencies from recurring in new equipment.

Technical Manual TO 00-35D-54 establishes the USAF Material Deficiency Reporting and Investigating System to implement the Product Improvement Policy of AFR 66-30. The procedures of the technical order apply to all USAF and USAF

supported agencies.

The purpose of the technical order is to

> establish a system that will feed back deficiency data on hardware, computer programs, clothing and textiles, to activities responsible for development, procurement, and other logistics management functions so that action can be initiated to correct and prevent maintenance, material, design and quality deficiencies (TO 00-35D-54, 1982, p. 1-1).

Deficiencies are reported to ASD program offices in the form of Service Reports (SRs). SRs are submitted while a program office has program management responsibility for a system in advanced development, engineering development, or operational use. Advanced development efforts which do not procure or fabricate hardware or software or are procured solely "to demonstrate concept feasibility and substantial configuration changes are expected prior to full-scale engineering development tests" are excluded from the reporting (TO 00-35D-54, 1982, p. 5-1).

According to the technical order, five different types of deficiencies can be reported:

> 1. Design Deficiency: Any condition that limits or prevents the use of material for the purpose intended or required where the material meets all other specifications or contractual requirements. These deficiencies cannot be corrected except through a design change.
>
> 2. Maintenance Deficiency: A deficiency which results in excessive maintenance man-hour consumption.
>
> 3. Material Deficiency: The failure of an end item which was attributable to neither the repair nor the manufacturing process, but was due to an unpredictable failure of an internal component or subassembly.

4. Quality Deficiency: A deficiency attributable to errors in workmanship, nonconformance to specifications, drawings, standards or other technical requirements, ommission of work operations during manufacture or repair, failure to provide or account for all parts, improper adjustment or other condition that can be identified as nonconformance to technical requirements of a work specification.

5. Software Deficiency: An error in the statements or instructions that comprise a computer program used by an imbedded computer system. The deficiency may consist of syntax, logic, or other discrepancies that cause the program to fail the intended functions (TO 00-35D-54, 1982, p. 1-2.)

Correction of four of the above types of deficiencies result in improvements that can be called reliability growth: design, material, quality, and software. Correction of maintenance deficiencies does not directly effect the reliability of equipment.

In addition to deficiency type, reports are also classified by severity:

Category I. A deficiency which may cause death, injury or severe occupational illness; would cause loss or damage to a weapon system; or directly restricts the combat readiness capabilities of the using organization.

Category II. A report of a defect which results in the failure of or prevents the use of an item, but which does not meet the criteria of Category I (TO 00-35D-54, 1982, pp. 1-2 - 1-3).

Normally, Category I SRs must be submitted to the program offices within 72 hours after finding the discrepancy. However, "serious safety of flight hazards will be reported by telephone no later than four hours after discovery". Category II SRs must be submitted within 15 calendar days after discovery (TO 00-35D-54, 1982, p. 3-1).

After receipt, the program office screens the SR to assure that it is correctly categorized. If the SR was erroneously reported, the program office negotiates with the originating activity before downgrading or returning the report.

Valid SRs are investigated as a Material Improvement Project (MIP). AFR 66-30 requires that a MIP be established by the command that has program management responsibility for the equipment in order to track, control, and document the investigation and correction of each deficiency (AFR 66-30, 1982).

An Air Force team analyzes the reported discrepancy and reports to a MIP review board. The board, made up of representatives from the program office, AFLC, ATC, and the operating command, acts as a working group to complete the investigation and recommend solutions. Periodic reviews of MIPs are performed to "make sure efficient, timely and the proper [sic] action is taken to correct deficiencies, and to discontinue MIPs of little or no value" (AFR 66-30, 1982, p. 2).

If the MIP board recommends a design or software change as a corrective action, the program office works with the contractor to make the change. Design or software corrections are usually handled through ECPs.

The SR/MIP process is a valuable tool to get

improvements resulting in reliability growth especially if there is no other formal program to seek reliability growth (as with the AGM-86B ALCM).

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